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DESIGN AND FABRICATION OF RADIATION DOSIMETRY INSTRUMENTS FOR TISSUE EQUIVALENT PLASTIC MANIKINS

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New Mexico

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ABSTRACT

An instrumentation system to measure the absorbed dose due to ionizing radiations has been designed for use with a tissue-equivalent manikin in space flights. The ionization chambers to be described are fabricated from tissue-equivalent materials to match those of the manikin and conform in design to the Bragg-Gray principle. Experimental curves show saturation conditions, pressure extrapolations, and directional dependence. Further, the design has minimized directional dependence with average losses ranging from 5 to 20 percent due to shielding of the first-stage electronics, which have been incorporated directly with the ionization chamber. The electrical signal generated by the radiation absorbed dose rate as recorded by the chambers is then processed electronically and telemetered back to earth. The electronic instrumentation functions continuously over a dose range of 0.01 to 100 rads per hour and has a logarithmic response. The chambers are designed to be placed in the tissue-equivalent manikin at the following sites: femur, abdomen, mediastinum, humeri, and spinal column. Automatic calibration is provided for in both the femur and abdomen electronics. The calibration data were obtained by using the gamma rays emitted by cobalt-60.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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I. INTRODUCTION

The objective of the work under this contract was the fabrication of three radiation dosimetry instruments to measure the absorbed dose rates at five locations in three tissue-equivalent plastic manikins which will be placed in a terrestrial orbit. The absorbed-dose monitoring locations in the manikin are the humeri (upper arm), femur, spinal column, abdomen, and mediastinum. The instruments were to be sensitive to gamma photons over the rate interval from 0.01 to 100 rad/h and were to have a voltage output approaching a logarithmic response.

Three prototype systems were fabricated and delivered. Each consists of five channels with interchangeable electronics. The femur and abdomen channels have automatic calibration. There are three basic sizes of ionization chambers: (1) the humeri and spinal column; (2) the femur, and (3) the abdomen and mediastinum.

II. PROCEDURE

It is well known in radiological physics that energy imparted to a material (in this case, muscle tissue) by ionizing radiation which includes secondary electrons ejected by photons may be determined by ionization measurements made in accordance with the Bragg-Gray principle. The ionization chambers of this system were designed to obey this principle. Therefore, they measured the energy imparted to muscle tissue regardless of the incident photon energy. Among the design considerations were a minimum use of metal in the chamber construction, tissue-equivalent walls, and small chamber cavity. Fig. 1 is a cross-sectional drawing of a typical chamber design and Fig. 2 is an assembly drawing of the same chamber.

A. Chamber Walls

The chamber walls consist of a muscle-tissue equivalent plastic, a conducting blend of materials with optimum mechanical properties, developed by Shonka.[1] Since there is little agreement in the literature on the composition of wet muscle, Shonka adopted the composition recommended by the International Commission of Radiological Units:

$$C_{1.024} \quad H_{10.2} \quad O_{4.556} \quad N_{0.25} \quad Na_{0.0035}$$

$$Mg_{0.0008} \quad P_{0.0065} \quad Si_{0.0756} \quad K_{0.0077} \quad Ca_{0.00017}$$

With this material surrounding a chamber cavity, one of the requirements for application of the Bragg-Gray principle is met.

B. Chamber Cavity

Another requirement for application of the Bragg-Gray principle is for the linear dimensions of the cavity to be less than the range of the secondary electrons generated in the wall material. As will be shown later, this requirement was also met. However, a limiting factor for reduction of the linear dimensions is that of maintaining adequate chamber volume for obtaining physically measurable ionization currents. The cavity volume for each chamber design is humeri and spinal column, 2.26 cm^3; femur, 8.14 cm^3; abdomen and mediastinum, 16.1 cm^3. The calculated ionization current per 0.010 rad/h energy absorption is 2.7×10^{-15}A, 9.6×10^{-15}A, and 1.9×10^{-14}A, respectively.

C. Guard Electrode

To insure accuracy in the measurement of the ionization currents, close attention was given to reduction of stray current leakage. To reduce the current leakage between the high voltage and collecting electrode, a guard electrode was placed between them. It is operated near the same potential as the collection electrode and thus is not a

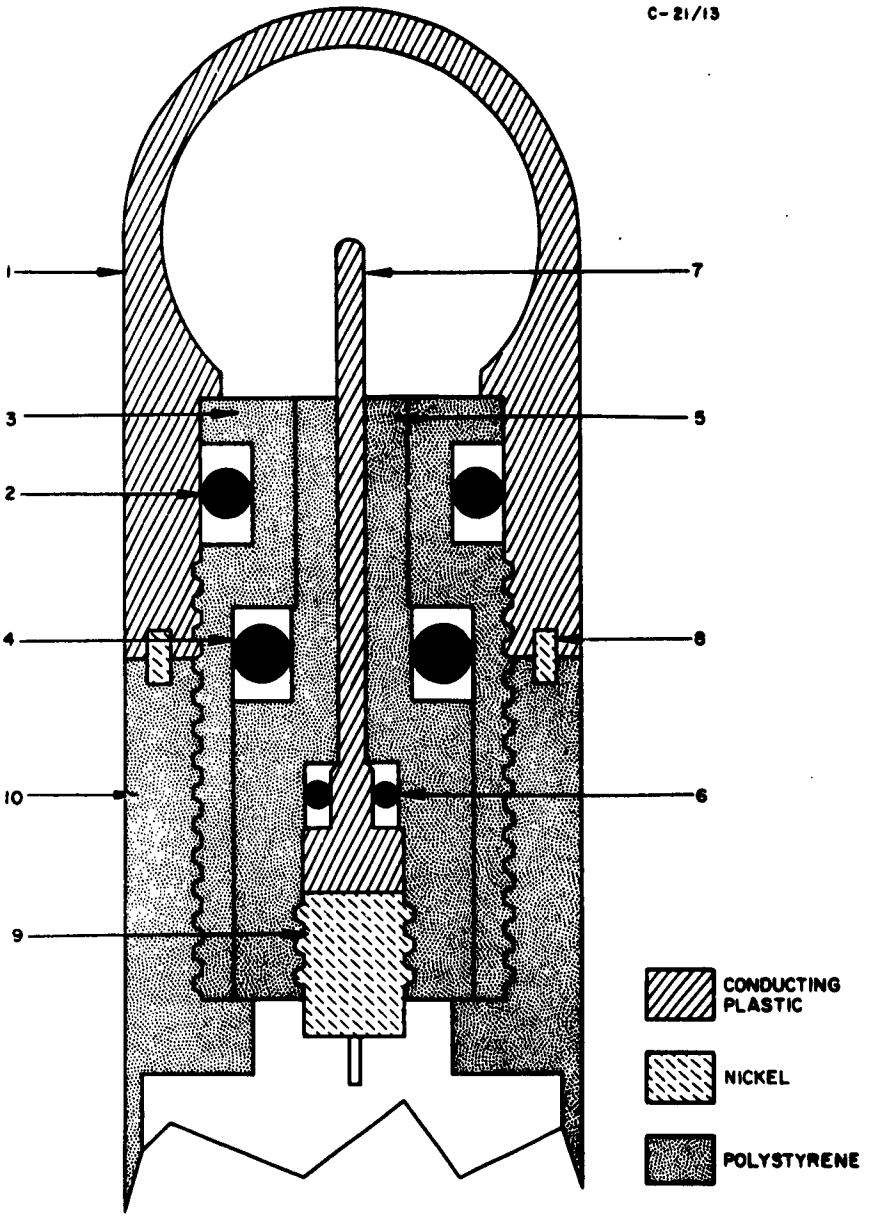
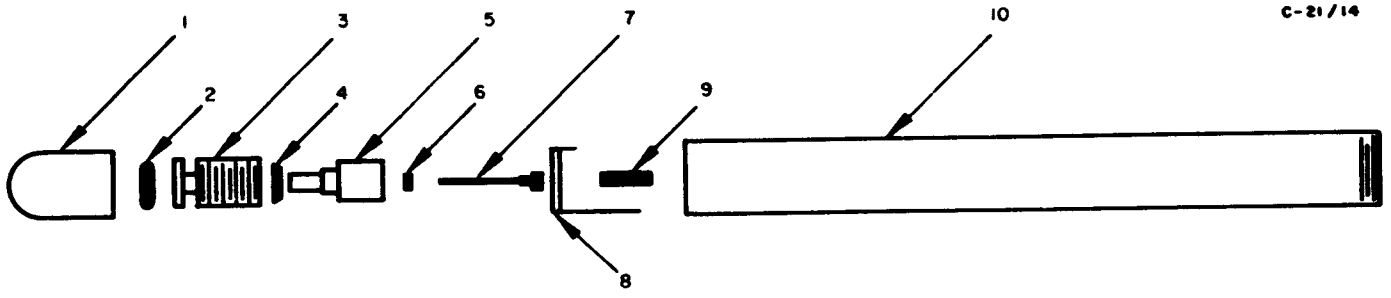


Fig. 1. Cutaway assembly of ionization chamber.



PT. NO.	NAME	MATERIAL
1	IONIZATION CHAMBER HV ELECTRODE	CON. PLASTIC
2	"O" RING	NAT. RUBBER
3	OUTER GLAND	POLYSTYRENE
4	"O" RING	NAT. RUBBER
5	MID-GLAND	POLYSTYRENE
6	"O" RING	NAT. RUBBER
7	IONIZATION CHAMBER COLLECTING ELECTRODE	CON. PLASTIC
8	HV CONDUCTOR	NICKEL
9	COLLECTING ELECTRODE CONDUCTOR	NICKEL
10	ELECTRONICS BARREL	POLYSTYRENE

Fig. 2. Assembly drawing of ionization chamber.

source of leakage. A measurement of the leakage current across the high-voltage-collecting-electrode gap revealed an effective impedance of $10^{17}\ \Omega$. With 70 V applied to the high-voltage electrode, the leakage current is two orders of magnitude less than that through the log diode at 0.010 rad/h.

D. Log Diode

To obtain a logarithmic response to radiation rate over a four-decade range, a log diode was used as the nonlinear element in the electronics. Fig. 3 is a block diagram of the electronics and represents an adaptation of the circuit developed by Wade.[2]

The log diode has characteristics described by

$$V = \frac{kT}{e} \log i + b \ ,$$

where

k ≡ Boltzmann's constant

e ≡ electronic charge

T ≡ cathode temperature

b ≡ constant depending on temperature.

This relationship between voltage and current is theoretically ideal for a logarithmic element if there are no changes in cathode temperature. The use of two such diodes properly connected, largely compensates for the effects of temperature changes and power supply variations.

E. Circuit Description

Fig. 4 is a schematic diagram of the log amplifier. Low-current electrometer tubes are used for the input stages. The balanced 5886 subminiature tubes drive a differential stage using 2N329A silicon transistors to obtain low I_{CO} and to minimize temperature effects. A stable operating level is obtained by connecting the electrometers as tetrodes and supplying the screen current from the common emitters of the transistors. The plate of the electrometer is connected to the bases of the transistors.

The current output of the differential stage is further amplified by two cascaded emitter-follower stages providing an over-all loop voltage amplification of 80. The dc level of the cascaded emitter-follower is then

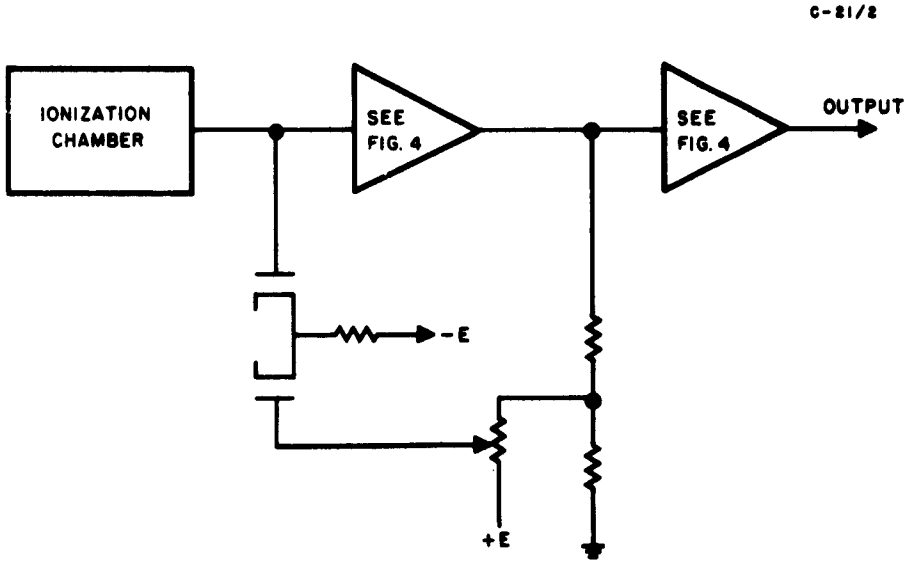


Fig. 3. Block diagram of the ionization chamber electronics.

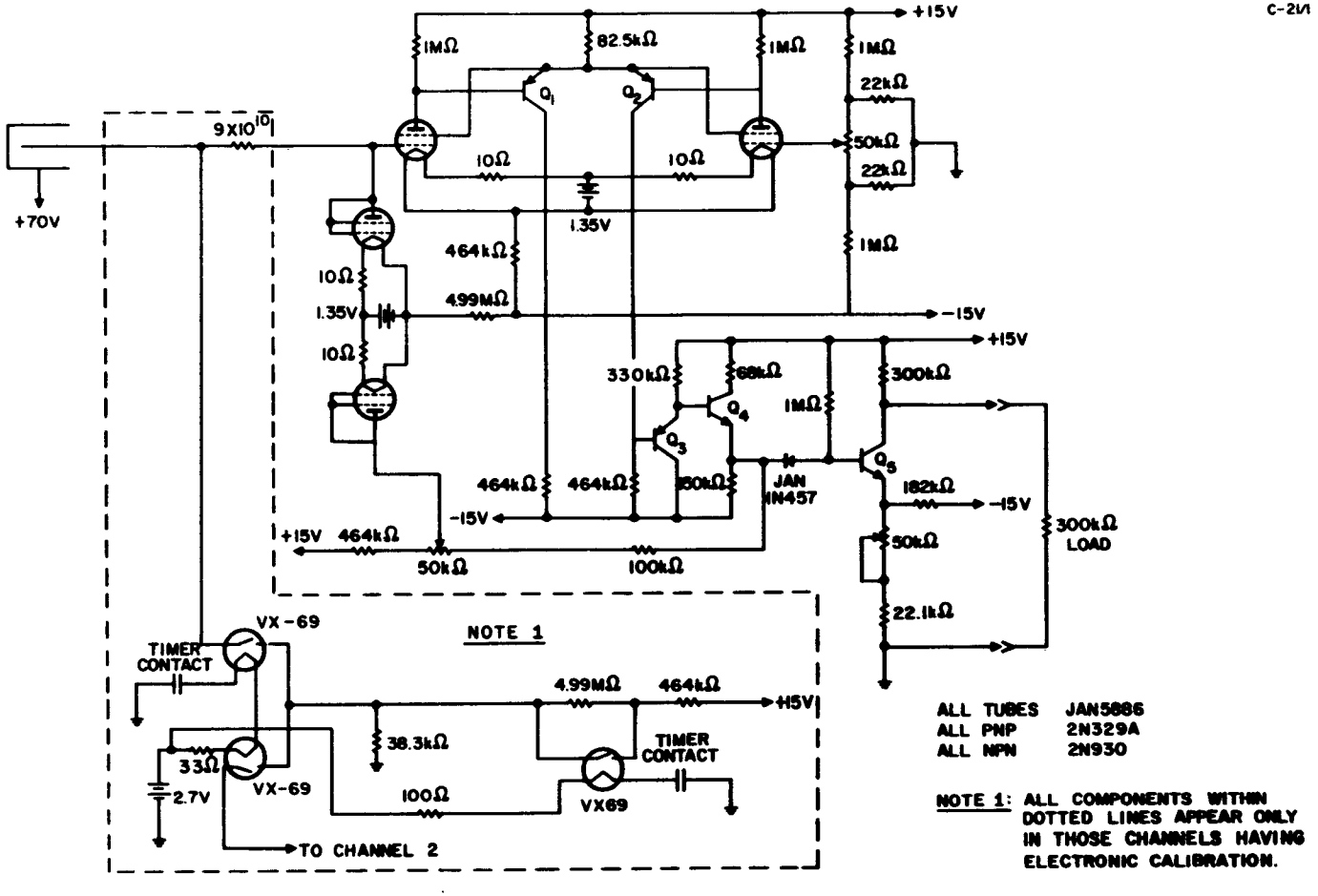


Fig. 4. Schematic of the electronic dc amplifier.

coupled to a 2N930 transistor to give a 0- to 5-V logarithmic output for measured input ranges of 0.010 to 100 rad/h. In this final stage, the output impedance is also matched to have minimum power supply current requirements when operating into a 300-k Ω load.

F. Automatic Calibration

To achieve automatic calibration of the electronics systems, a high-meg (9×10^{10} Ω) resistor and a thermal relay were included in the electronics of two of the radiation-monitoring channels. The thermal relay periodically attaches fixed voltages from a low-impedance source to the ionization chamber end of the high-meg resistor (Fig. 4). In this manner, a current source which does not appreciably affect the feedback current through the log diode is approximated. Therefore, electronic drifts can be compensated for in the received data.

III. TEST RESULTS

A. The Bragg-Gray Criteria

In the Bragg-Gray theory of the cavity ionization chamber, the assumption is made that the secondary electrons traversing a solid medium lose the same amount of energy in a distance ΔX, which is short compared with their range, as they would lose in traversing a distance $S\Delta X$ of air, where S is a proportionality factor that is independent of the particle velocity.[3] Therefore, if the geometry of an ionization chamber design is such that the cavity width is comparable to the range of the particle in air, it becomes impossible to relate accurately the ionization produced in the cavity to the absorbed tissue dose at the point of measurement. An experimental check of the cavity design criteria is therefore necessary. This check is made by measuring the ionization per unit mass of air in the cavity as the pressure is reduced. If this measurement yields a constant value, it is known that the secondary electrons lose only a small fraction of their energy in traversing the cavity and, therefore, the design criterion has been met.

In the experiment, the cavity pressure was reduced while the ionization chamber was exposed to a constant radiation rate. The data obtained indicated the amount of ionization current versus cavity pressure. Since the temperature and volume are constant, division of the indicated ionization current by the cavity pressure yields a value that is proportional to the ionization current per unit mass of air. Figures 5(a), (b), and (c) show that this value tends to remain constant as pressure is reduced for each chamber design.

B. Directional Dependence

Outer space radiation can be considered isotropic for dosimetry purposes. Therefore, if the energy absorption sensors are directionally dependent, it is necessary to correct the indicated radiation absorption dose rates. As can be seen from Fig. 6, the average response of the abdomen-type chamber, taken over all incident angles, is 95 percent of that for its most sensitive direction, for which the calibrated absorbed dose rate curve was obtained. Therefore, if the chamber is placed in an isotropic radiation field, the indicated absorbed dose rate must be corrected by the factor 1.05 (the reciprocal of 0.95) to account for the nonuniform directional sensitivity shown in Fig. 6. Similar correction factors of 1.12 and 1.20 should be made for the femur- and humeri-type chambers, whose directional characteristics are presented in Figs. 7 and 8.

The preceding correction factors are true only when the ionization chambers are placed by themselves in an isotropic field and, therefore, a similar measurement must be made when the chambers are placed in

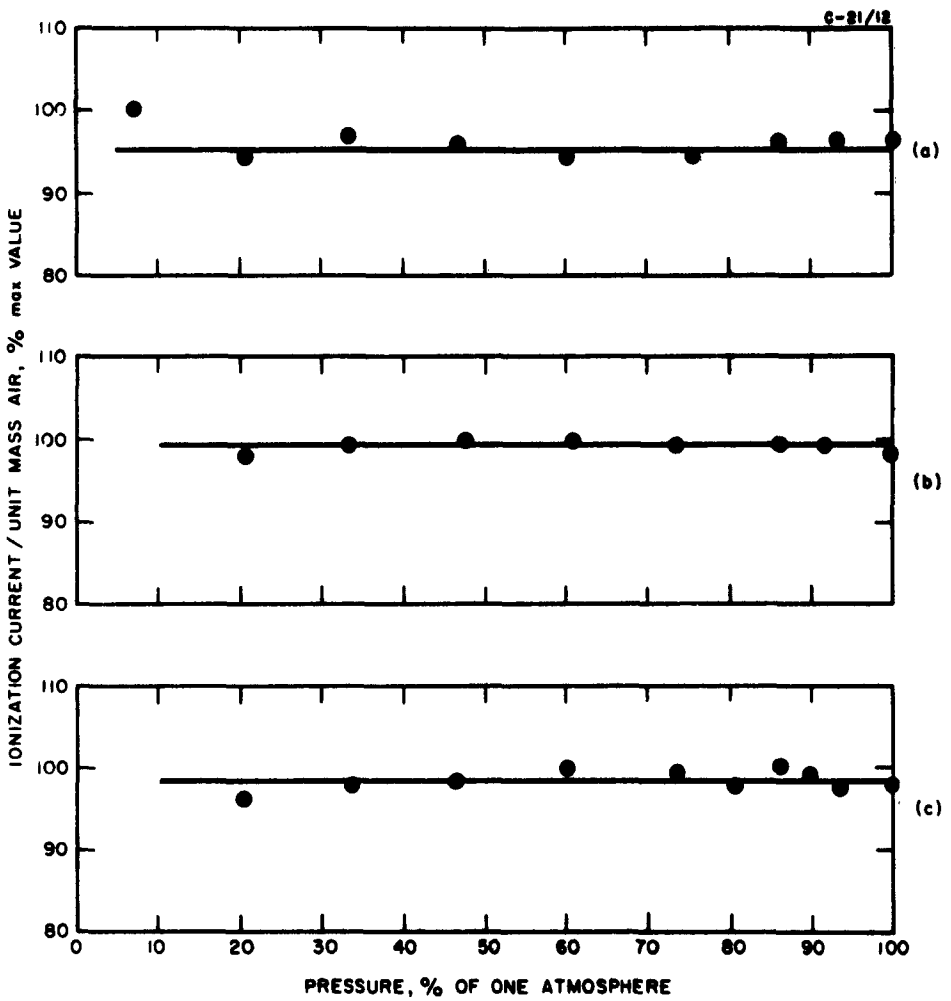


Fig. 5. Ionization current per unit mass of air versus cavity pressure. (a) Humeri-type chamber; (b) Femur-type chamber; (c) Abdomen-type chamber.

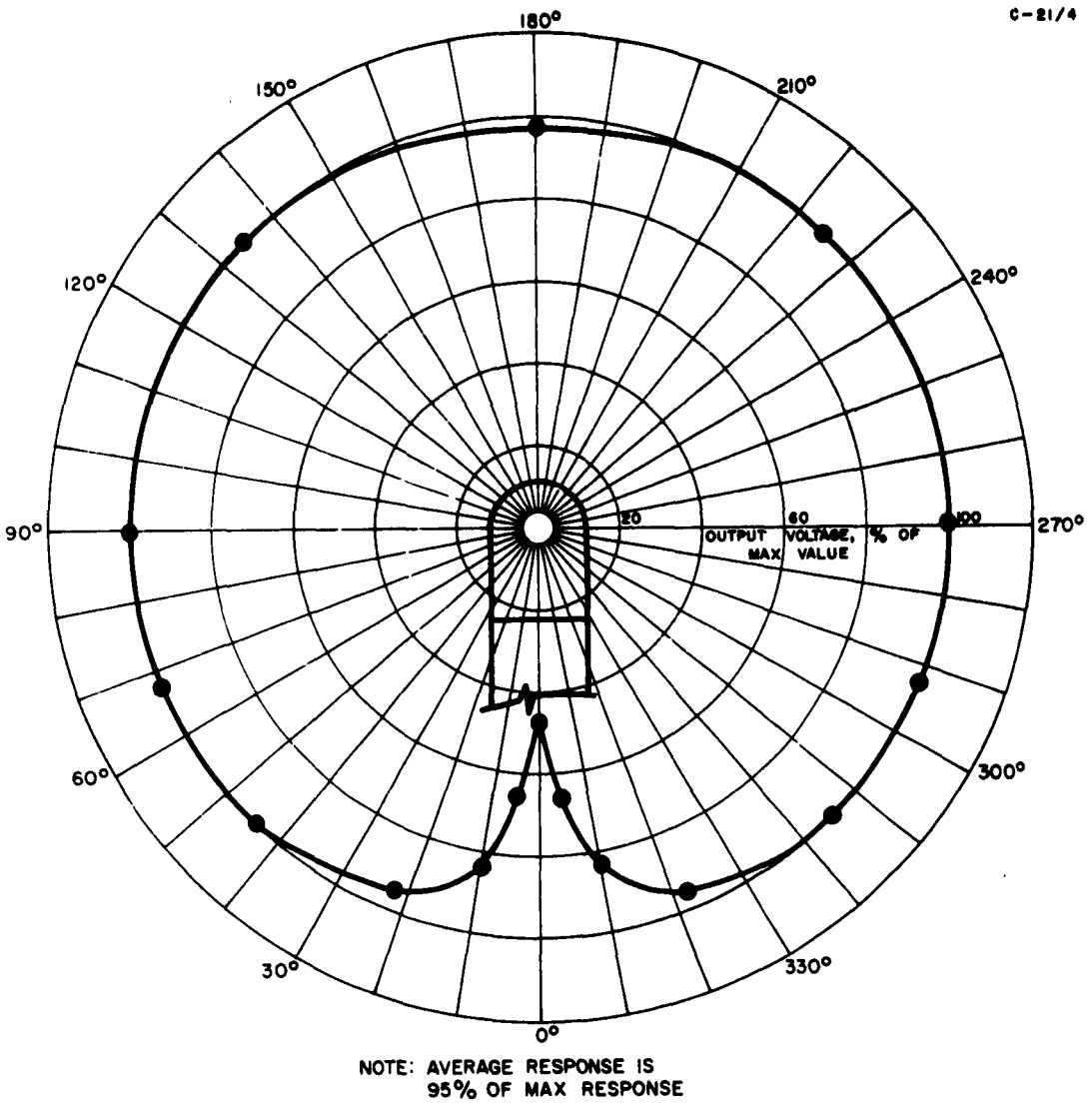


Fig. 6. Directional sensitivity of the abdomen-type ionization chamber to Co^{60} gamma radiation.

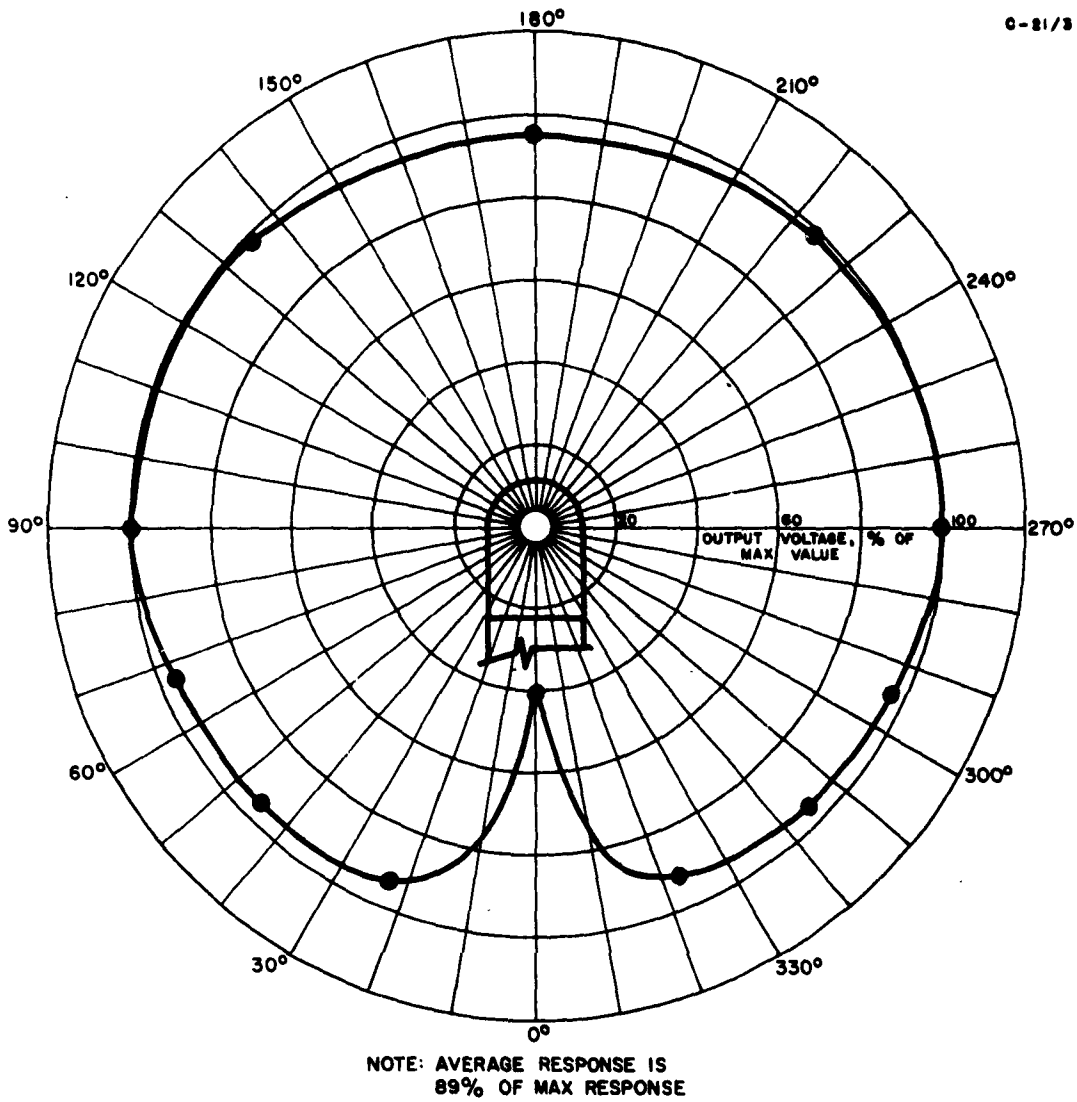


Fig. 7. Directional sensitivity of the femur-type ionization chamber to Co^{60} gamma radiation.

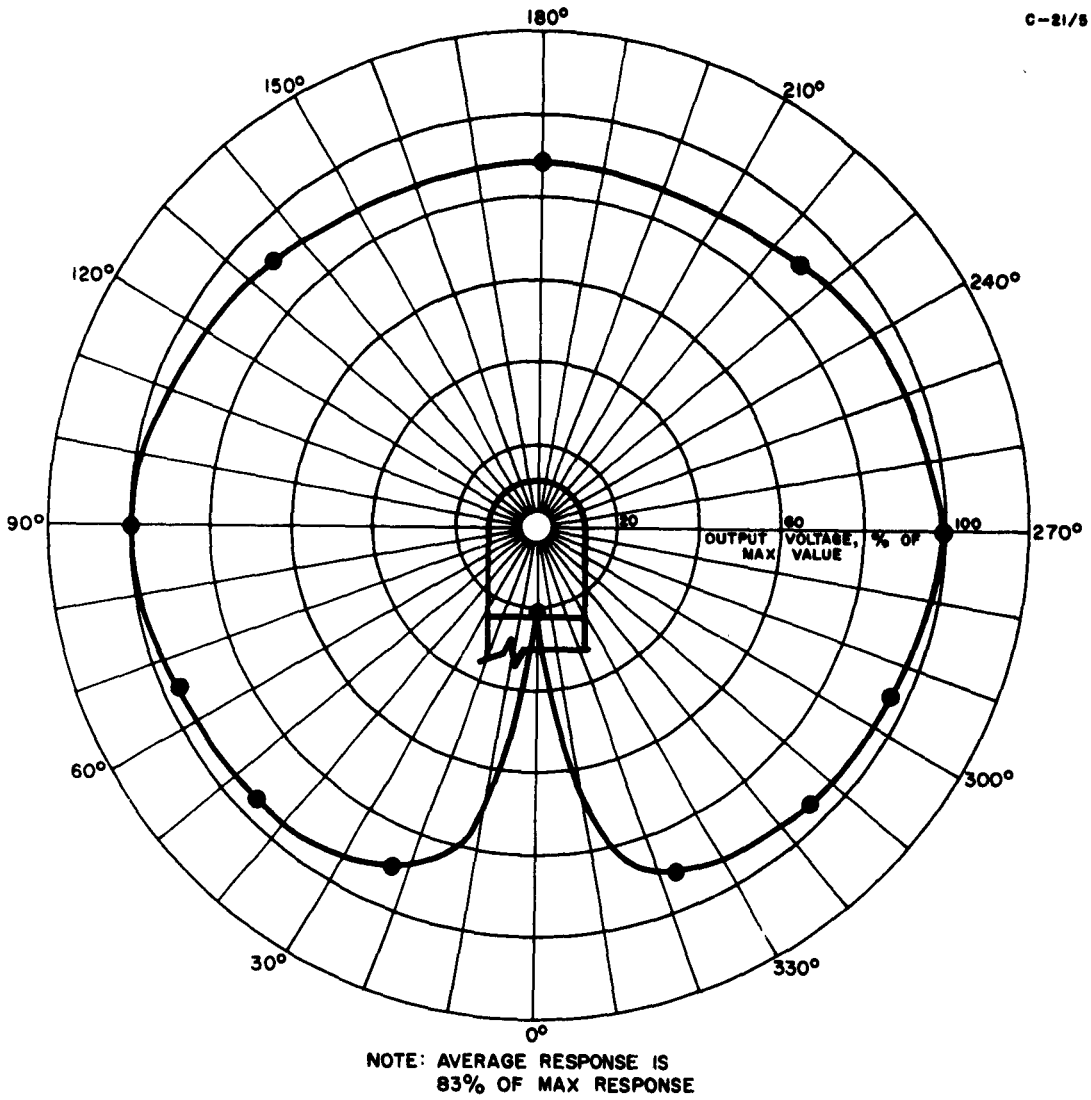


Fig. 8. Directional sensitivity of the humeri-type ionization chamber to Co^{60} gamma radiation.

scattering media such as the tissue equivalent plastic manikin. Two entities will change the correction factors for the latter case. (1) The differential absorption by the manikin will create anisotropy of the radiation field. (2) The differential scattering by the manikin components will alter the shape of the directional curve.

C. Saturation Voltage

To achieve maximum collection of the ionization current, each chamber design was checked for indicated collection current versus high-voltage electrode potential. Figures 9, 10, and 11 are graphs of these measurements.

It will be noted that the highest potential required for maximum collection current is 30 V (see Fig. 11). Therefore, the chosen 70-V high-voltage supply is ample to ensure both maximum collection current and insensitivity to long-term changes in high-voltage-supply potential.

D. Calibration

Calibration of each channel was obtained by using a Co^{60} needle with an accurately known activity of 11.8 mC and a length of 1 cm. Experiments showed that at distances greater than 13 cm, the ionization chambers behaved as $1/r^2$ detectors for this Co^{60} source. Therefore, the Co^{60} needle can be considered to be a point source for greater distances. At a separation distance of 17.5 cm, the calculated exposure dose rate is 0.52 r/h. Reduction[4] by 4% then gives a tissue absorbed dose rate of 0.5 rad/h.

When the output of a point-source x-ray generator is adjusted to give the same electronic output at a separation distance of 7.2 m as that obtained from exposure to the standard source at 17.5 cm, 0.5 rad/h is again obtained. The inverse square relationship shows that 100 rad/h is obtained at a 0.5-m separation, thereby giving full range calibration capabilities. Figures 12 through 14 are typical calibration curves for each chamber design.

E. Response Times

The intended use of these instruments requires a telemetry link, and link-generated noise will degrade the data. It is possible to recognize noise by knowing the system response time to changes in the measured parameter. Thus, when the data indicate changes in excess of the system response time, they may be discounted.

The system response time to step changes in radiation rate was measured for each chamber design. Since the response time is inversely proportional to the amount of electronic feedback, a set of data is required

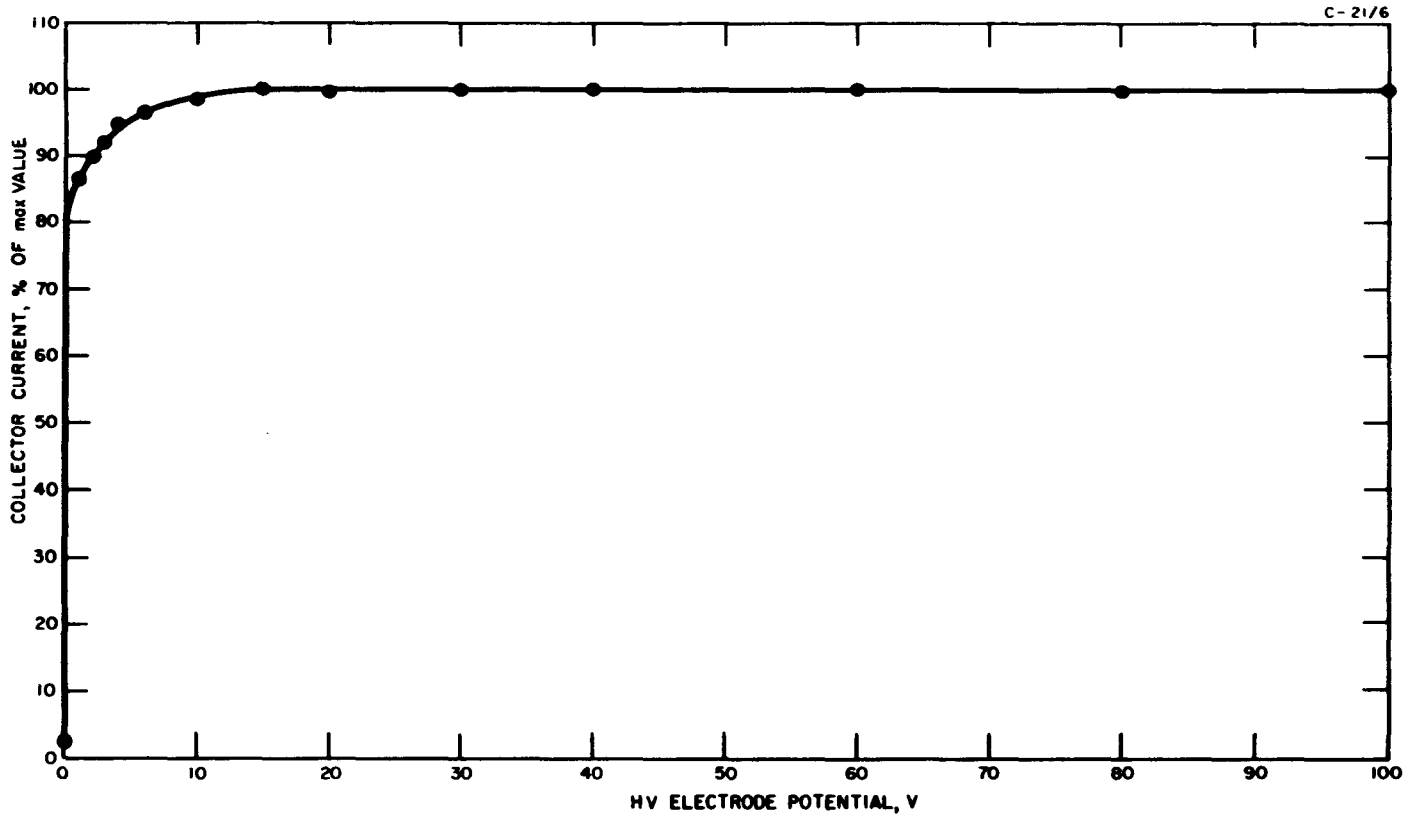


Fig. 9. Saturation voltage curve for the humeri-type ionization chamber.

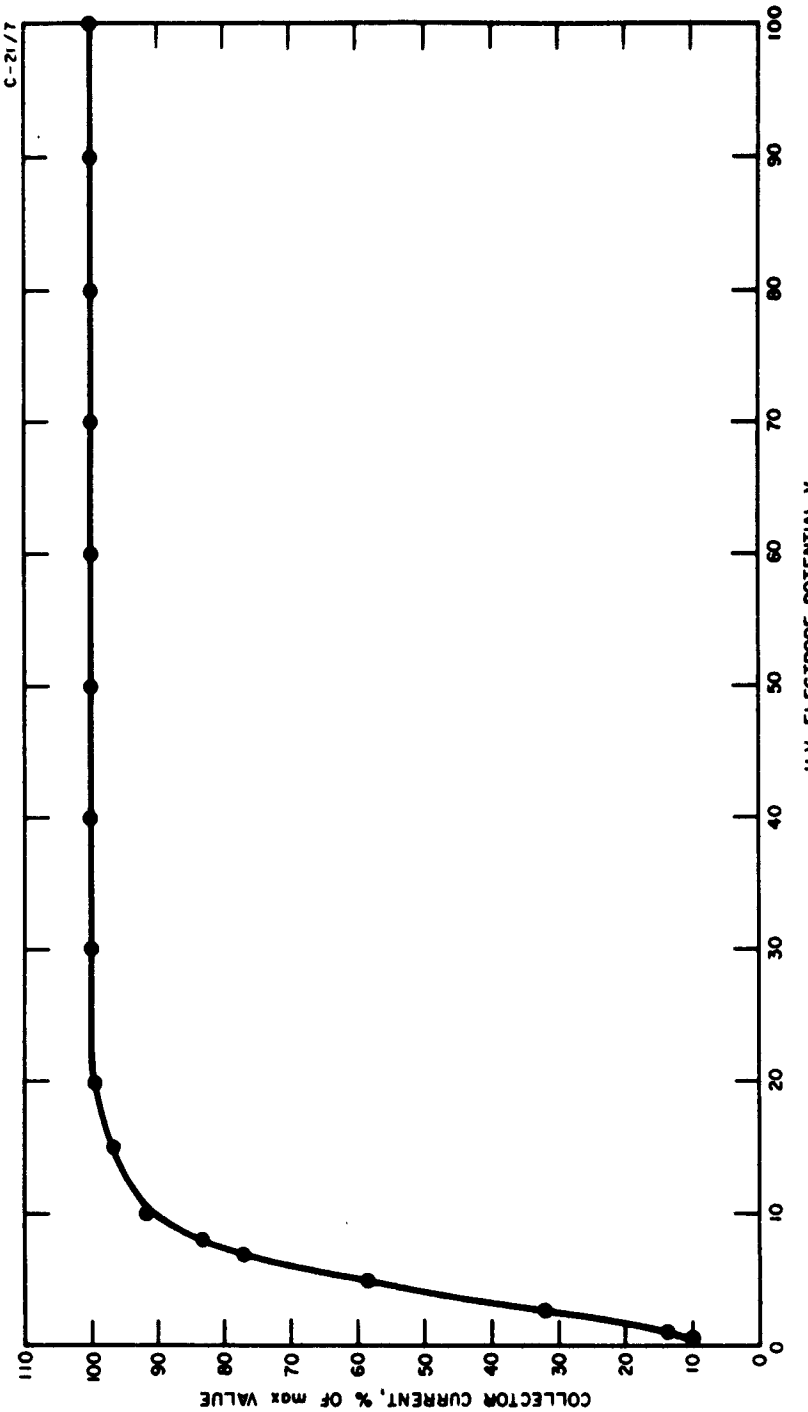


Fig. 10. Saturation voltage curve for the femur-type ionization chamber.

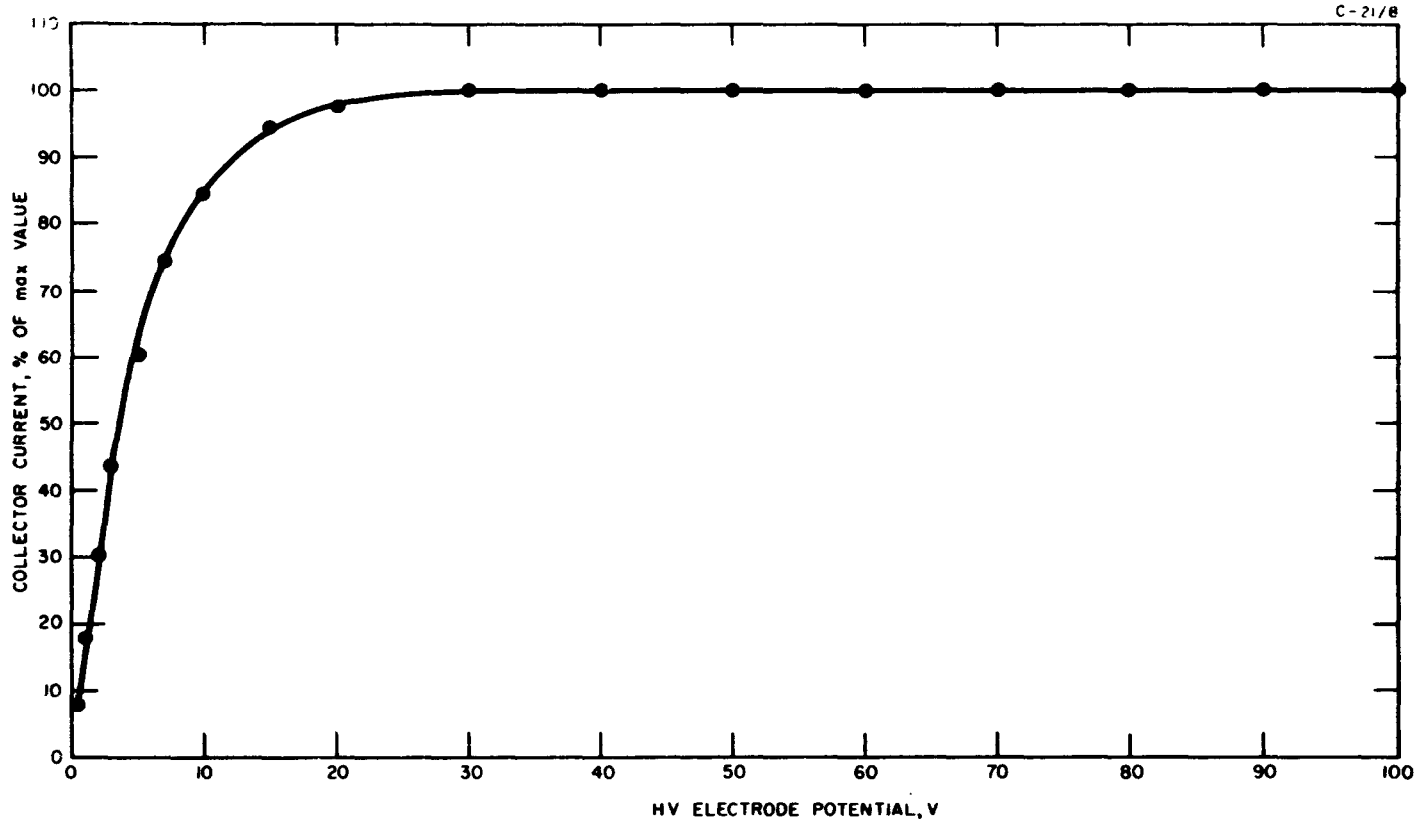


Fig. 11. Saturation voltage curve for the abdomen-type ionization chamber.

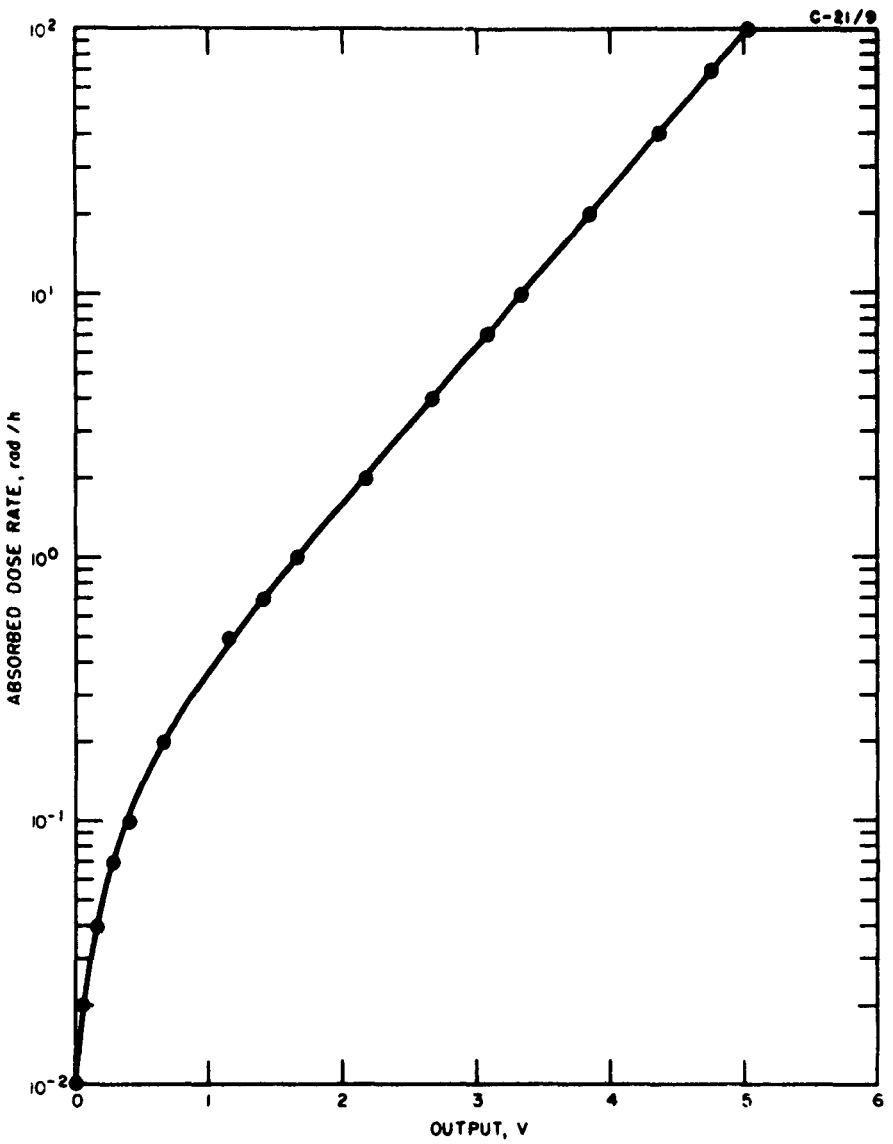


Fig. 12. Calibration for the humeri-type ionization chamber.

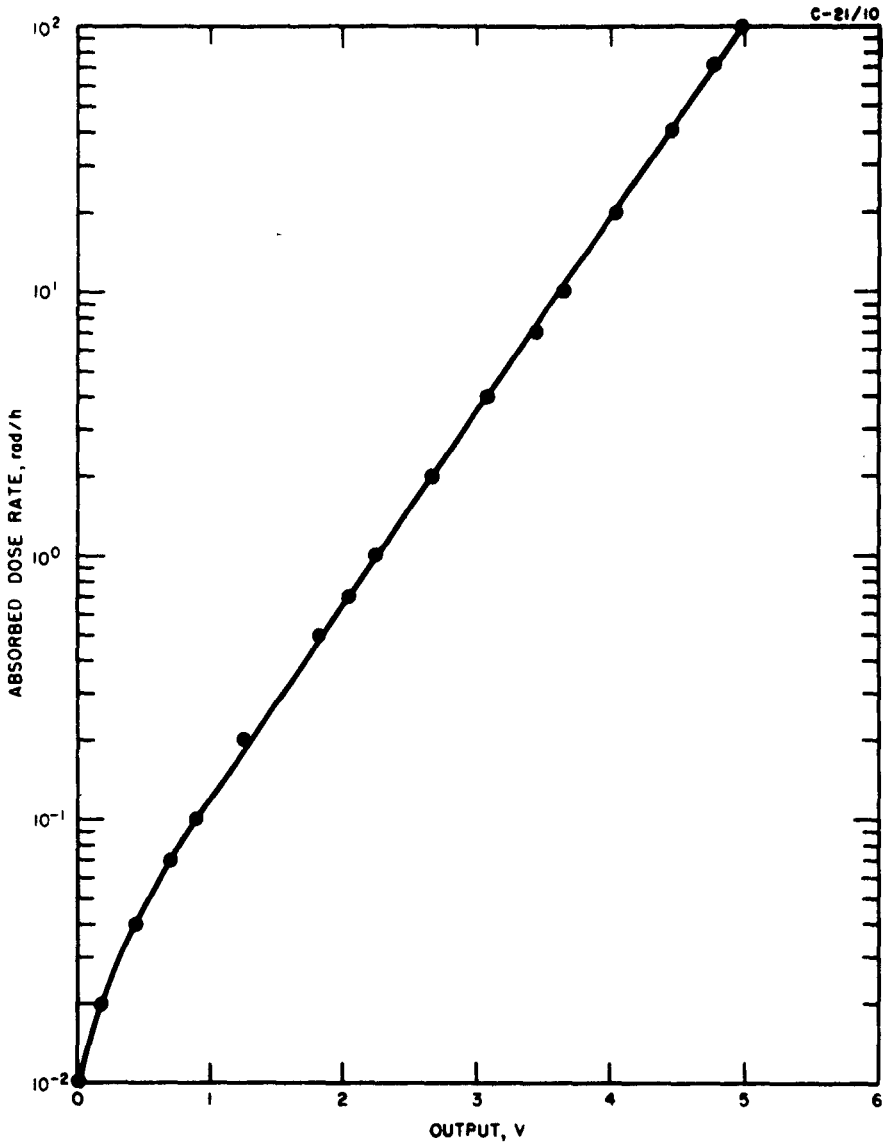


Fig. 13. Calibration for the femur-type ionization chamber.

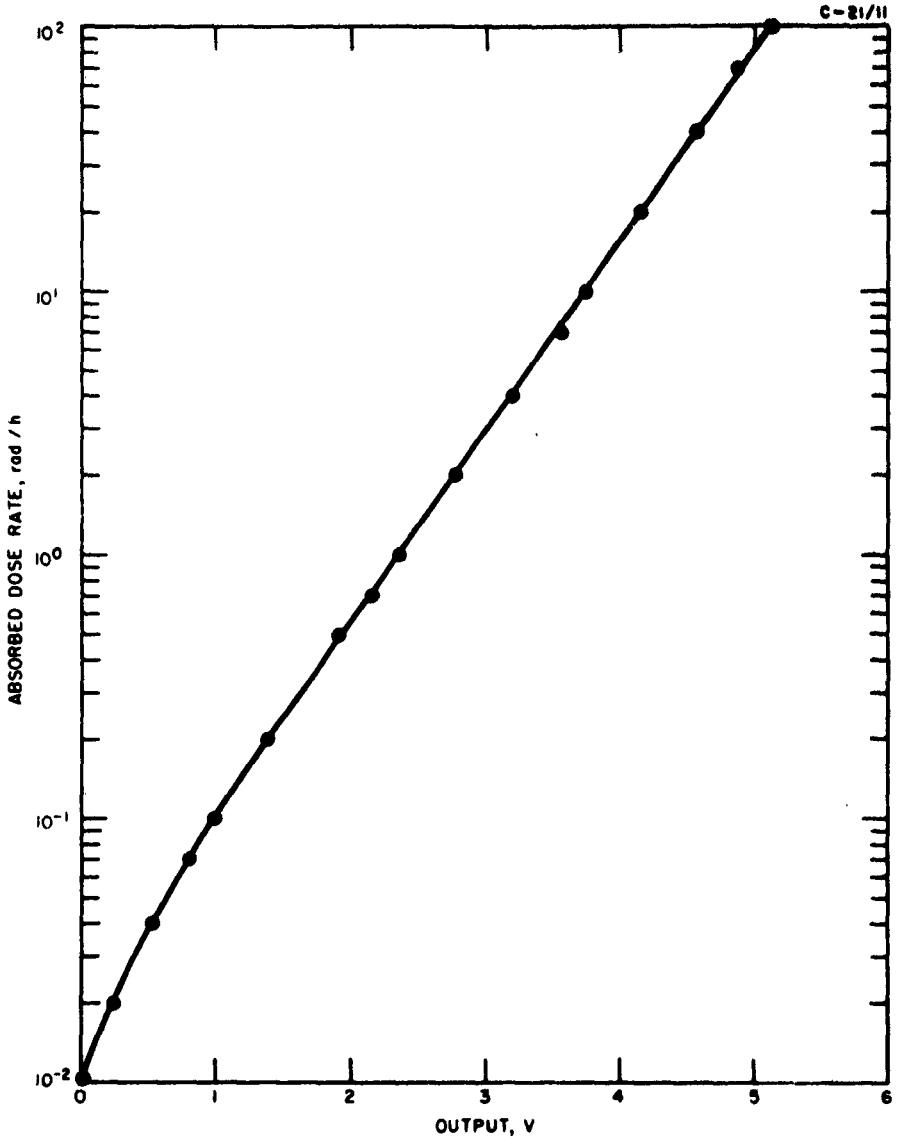


Fig. 14. Calibration for the abdomen-type ionization chamber.

for each chamber. In Table I, data are recorded for the time required for both increasing and decreasing changes in energy absorption rate for the output voltage to reach 90% of equilibrium value.

F. Qualification Tests

Prior to system assembly, four critical components were subjected to qualification tests. These were the 5886 electrometer tubes, the VX 69 thermal relay, the SL11DA relay, and the collecting electrode of the ionization chamber. The test for the first three items is described below, and the results are given.

The test specimens were mounted on a centrifuge in three successive positions so that each of the three major axes of the test specimens, in turn, extended in a radial direction with respect to the centrifuge center of rotation. The acceleration, starting from zero, was increased to 40 g's in approximately 2 min and held for a period of no less than 10 min.

For the SL11DA relays, three specimens were wired so that all normally closed contacts were in series and were tested for contact opening in excess of 0.01 msec; no malfunctions were detected in the relays during the tests.

For the VX 69 thermal relay, the activation-deactivation voltages and currents of four specimens were tested. These data are tabulated in Table II for each test specimen prior to and after the acceleration environment. The observed changes are insignificant compared with the supply voltage of 1.25 V in system operation.

For the 5886 electrometer tube, six specimens were wired so that changes in plate current could be detected during acceleration while all electrode potentials were held constant. There were no detectable changes in plate current in any of the test specimens.

The mechanically weakest component of the ionization chamber is thought to be the collection electrode. Therefore, this item was given the following vibration and shock test, in which no visible damage was noted.

A 1.7-in. and 1.1-in. extension of a 0.100- and 0.050-in.-diameter conducting plastic rod, respectively, was subjected to a white noise vibration in which the spectrum was weighted according to the following:

5 to	50 cps	±	0.4 g rms
50 to	430 cps	±	1.0 g rms
430 to	510 cps	±	2.0 g rms
510 to	700 cps	±	7.0 g rms
700 to	2000 cps	±	2.0 g rms

TABLE I

Times Required for Output Voltage to Reach 90% of Equilibrium Output Voltages for Various Step Changes in Energy Absorption Rate

Output Voltage Interval, V	Humeri		Femur		Abdomen	
	Increasing, sec	Decreasing, sec	Increasing, sec	Decreasing, sec	Increasing, sec	Decreasing, sec
0 - 5	< 1	17	1	21	< 1	10
0 - 4.5	< 1	20	1	21	< 1	11
0 - 3.5	< 1	21	1	19	< 1	12
0 - 3.0	1.9	24	1	19	< 1	14
0 - 2.5	3.7	26	2	18	< 1	15
0 - 2	5	31	3	19	2	18
0 - 1.5	10	32	5	23	4	20
0 - 1.0	17	33	10	24	9	22
0 - 0.5	27	37	22	26	23	30
1 - 0.5	19	28	10	19	9	17
1.5 - 1	8	9	5	6	3	5
2 - 1.5	4	6	3	3	< 1	2
2.5 - 2	2	4	2.5	3	< 1	< 1
3 - 2.5	1	2	2	3	< 1	< 1
3.5 - 3	< 1	< 1	2	3	< 1	< 1
4 - 3.5	< 1	< 1	2	3	< 1	< 1
4.5 - 4	< 1	< 1	2	2	< 1	< 1
5 - 4.5	< 1	< 1	2	2	< 1	< 1

In addition, these pieces were given a separate sinusoidal vibration of:

5	to	20 cps	0.25-in. double amplitude
20	to	50 cps	3 g's
50	to	500 cps	9 g's
500	to	2000 cps	15 g's

with the sweep rate of the shake table 2 min/octave. Finally, there was a shock acceleration of 30 g's in 9 msec. All of these tests were performed with the pieces held so that maximum force was perpendicular to the axis of symmetry.

System environmental tests were performed as indicated in Appendix VII.

TABLE II

VX 69 Thermal Relay Characteristics before and after 40 g's Acceleration

	Prior to Acceleration				After Acceleration			
	Activation		Deactivation		Activation		Deactivation	
Relay Number	Voltage, V	Current, mA	Voltage, V	Current, mA	Voltage, V	Current, mA	Voltage, V	Current, mA
1	0.557	7.5	0.538	7.2	0.574	7.8	0.522	7.2
2	0.501	6.5	0.435	5.8	0.475	6.0	0.400	5.6
3	0.529	7.0	0.475	6.4	0.522	6.8	0.478	6.5
4	0.620	8.1	0.609	8.0	0.778	10.0	0.742	9.6

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4. NBS Handbook No. 62 (Government Printing Office, Washington, D.C., April 1957).

APPENDIX I – TEST SPECIFICATION
DC AMPLIFIER MODULE
SCHEMATIC NO. 334545
334544-400

A. Test Preparations

1. Connect module to test circuit shown in Fig. A-1. Note precautions shown on this figure. Allow at least 1/2-h warm-up time.

B. Tests

1. Balance Test

Set potentiometer R11* for 0 V dc at TP3. Turn R26 fully counterclockwise (minimum gain) and R21 fully clockwise. These three potentiometers must be adjusted so that the following three conditions are satisfied:

a. When point A is connected to point B, and switch S1 is in position 1, the output voltage at TP1 shall be between 0 and 2.5 V dc.

b. When point A is connected to point B, and switch S1 is in position 2, the output voltage at TP1 shall be between 4.8 and 5.0 V dc.

c. When point B is disconnected from point A, and left open, the output voltage at TP1 shall be 0 ± 0.02 V dc after reaching equilibrium.

When making the above adjustments, R26 should be used primarily to adjust the range or total variation of output voltage, while R11 and R21 should be used to meet the other two conditions. The final setting of R11 should be such that the voltage at TP3 is within ± 0.4 V from ground.

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*During initial factory checkout, either resistor R12 or R13 may be removed to secure sufficient adjustment range in the positive or negative direction for potentiometer R11. If any of the tubes or transistors on the module are replaced, it is necessary to redetermine the proper resistor to be removed.

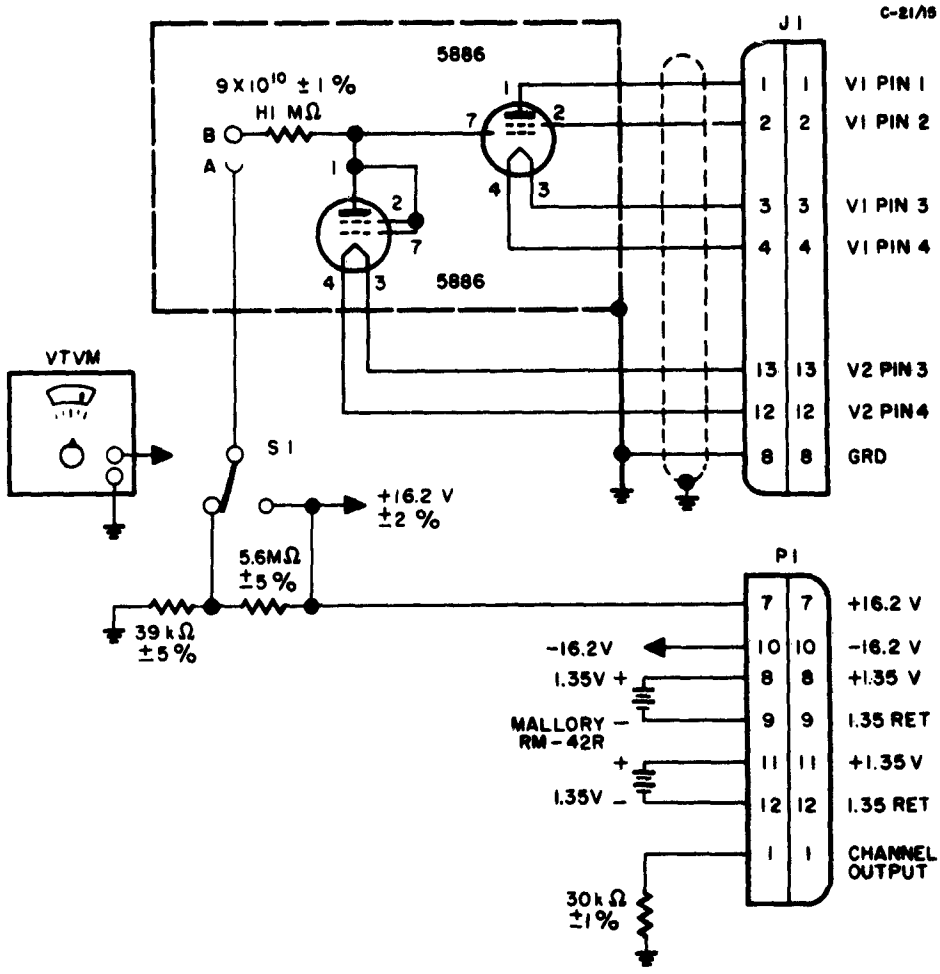

Fig. A-1. Recommended test setup.

2. Continuity and Resistance Tests

Check for continuity (less than 2 Ω) between the following points:

P1-4 and J1-11
P1-5 and J1-10
P1-6 and J1-9
J1-5, 6, 7, and 8

Check resistance between P1-3 and J1-14. This resistance shall be 1.0 MΩ ± 10%.

APPENDIX II – TEST SPECIFICATION RADIATION DOSIMETER POWER SUPPLY UNIT SCHEMATIC NO. 334534 334532-400

A. Test Equipment

Vacuum tube voltmeter, Electro-Instruments Model 1050, or equivalent
Multimeter, Simpson Model 260, or equivalent
Carbon resistors, 1/2 W, 5%, 68Ω and 220Ω
Stop Watch

B. Test Preparations

Connect the 220-Ω resistor from J1, pin 5 to J2, pin 6. Momentarily connect +28 V dc between TP1 and TP3 to activate the latching relays.

C. Tests

1. Timer Test

Connect the VTVM to TP4 to observe the timing and calibrate cycle. Connect the multimeter to TP5. Allow the timer to operate 3 min or longer before beginning measurements.

The voltage at TP5 will switch from approximately 2.7 V dc to approximately 0.5 V dc. Measure the length of time in each condition. The length of time in the high-voltage condition shall be between 70 and 90 sec. The length of time in the low-voltage condition shall be between 35 and 45 sec.

While the voltage at TP5 is in the low condition, the calibrating voltage at TP4 shall switch between 0.113 ± 5% and 1.24 ± 5% V dc. The length of time in each condition shall be between 9 and 13 sec.

While the voltage at TP5 is in the high condition, the calibrating voltage at TP4 shall not switch, but may remain at either voltage.

2. Battery Test

Check that battery voltages appear at the proper points as indicated in schematic 334534. The 1.35-V batteries used for filament voltage should be checked with a load of 68 Ω across the multimeter terminals. Applicable tolerances are as follows:

Nominal voltage	Tolerance limits
16.2	15 to 17.5
10.8	10 to 12
1.35	1.3 to 1.4
2.7	2.6 to 2.8
67	63 to 72

D. Wiring

Using a multimeter, or other continuity indicating device, check the remainder of the circuit and connections to the plugs and test points as shown on Schematic 334545. This procedure must be performed with caution because batteries are in the equipment, with voltages always present.

E. Post Test Procedure

Momentarily connect +28 V dc between TP2 and TP3 to deactivate the latching relays.

APPENDIX III – TEST SPECIFICATION
RADIATION DOSIMETER PROBE, UNIT 3, TYPE I
SCHEMATIC NO. 334553
334553-400

A. Test Equipment

Electromagnetic radiation source having energies greater than 100 keV and capable of producing exposure dose rates of between 0.010 and 105 r/h.
Radiation dosimeter power supply as outlined by test specification 334532-400.
Dc amplifier module as outlined by test specification 334544-400.
Vacuum tube voltmeter, Electro-Instruments Model 1050, or equivalent.
Carbon resistor, 1/4 W, 5%, 300 k Ω.

B. Test Preparations

1. Connect the 300-kΩ resistor from TP1 of the dc amplifier module to chassis ground. Connect the VTVM across the resistor. Connect P1 of the dc amplifier to either J3, 4, or 5 of the radiation dosimeter power supply. Momentarily connect +28 V dc between TP1 and TP3 of the power supply to activate the latching relays. Allow at least 1/2-h warm-up time.

2. Adjust R26 (gain) and R21 (zero) of the dc amplifier module so that 0 and +5 V are indicated by the VTVM for exposure dose rates of 0.0104 and 104 r/h, respectively.

C. Tests

1. Collection Current Leakage Test

The VTVM should indicate no less than +1 V when the ionization chamber cavity is exposed to a 0.52-r/h exposure dose rate emanating from the electromagnetic radiation source.

2. Logarithmic Response Test

The voltage outputs between +1.0 and +5.0 V for exposure dose rates between 0.417 and 104 r/h should not vary more than ± 0.20 V from that predicted by

$$E_{out} = K(1 + \log R) ,$$

where

$K = 1.66$ V

R = numerical value of exposure dose rate in r/h.

3. Response Time Test

The output voltage should reach 1.35 V in less than 15 sec when exposed to a step change in radiation rate of from 0 to 0.83 r/h.

D. Post Test Procedure

Momentarily connect +28 V dc between TP2 and TP3 of the power supply to deactivate the latching relays.

APPENDIX IV – TEST SPECIFICATION
RADIATION DOSIMETER PROBE, UNIT 5, TYPE III
SCHEMATIC NO. 334577
334577-400

A. Test Equipment

Electromagnetic radiation source having energies greater than 100 keV and capable of producing exposure dose rates of between 0.010 and 105 r/h.
Radiation dosimeter power supply as outlined by test specification 334532-400.
Dc amplifier module as outlined by test specification 334544-400.
Vacuum tube voltmeter, Electro-Instruments Model 1050, or equivalent.
Carbon resistor, 1/4 W, 5%, 300 kΩ .

B. Test Preparations

1. Connect the 300-kΩ resistor from TP1 of the dc amplifier module to chassis ground. Connect the VTVM across the resistor. Connect P1 of the dc amplifier to either J3, 4, or 5 of the radiation dosimeter power supply. Momentarily connect +28 V dc between TP1 and TP3 of the power supply to activate the latching relays. Allow at least 1/2-h warm-up time.

2. Adjust R26 (gain) and R21 (zero) of the dc amplifier module so that 0 and +5 V are indicated by the VTVM for exposure dose rates of 0.0104 and 104 r/h, respectively.

C. Tests

1. Collection Current Leakage Test

The VTVM should indicate no less than +1.6 V when the ionization chamber cavity is exposed to a 0.52 r/h exposure dose rate emanating from the electromagnetic radiation source.

2. Logarithmic Response Test

The voltage outputs between +1.0 and +5.0 V for exposure dose rates between 0.135 r/h and 104 r/h should not vary more than ± 0.20 V from that predicted by

$$E_{out} = K(1.6 + \log R) ,$$

where

K = 1.4 V

R = numerical value of exposure dose rate in r/h.

3. Response Time Test

The output voltage should reach 1.35 V in less than 15 sec when exposed to a step change in radiation rate of from 0 to 0.31 r/h.

D. Post Test Procedure

Momentarily connect +28 V dc between TP2 and TP3 of the power supply to deactivate the latching relays.

APPENDIX V – TEST SPECIFICATION
RADIATION DOSIMETER PROBE, UNIT 1, TYPE II
SCHEMATIC NO. 334566
334566-400

A. Test Equipment

Electromagnetic radiation source having energies greater than 100 keV and capable of producing exposure dose rates of between 0.010 and 105 r/h.
Radiation dosimeter power supply as outlined by test specification 334532-400.
Dc amplifier module as outlined by test specification 334544-400.
Vacuum tube voltmeter, Electro-Instruments Model 1050, or equivalent.
Carbon resistor, 1/4 W, 5%, 300 kΩ.

B. Test Preparations

1. Connect the 300-kΩ resistor from TP1 of the dc amplifier module to chassis ground. Connect the VTVM across the resistor. Connect P1 of the dc amplifier to either J1 or 2 of the radiation dosimeter power supply. Connect TP4 to TP3 of the power supply to short out the automatic calibration voltage. Momentarily connect +28 V dc between TP1 and TP3 of the power supply to activate the latching relays. Allow at least 1/2-h warm-up time.

2. Adjust R26 (gain) and R21(zero) of the dc amplifier module so that 0 and +5 V are indicated by the VTVM for exposure dose rates of 0.0104 and 104 r/h, respectively.

C. Tests

1. Collection Current Leakage Test

The VTVM should indicate no less than +1.5 V when the ionization chamber cavity is exposed to a 0.52-r/h exposure dose rate emanating from the radiation source.

2. Logarithmic Response Test

The voltage outputs between +1.0 and 5.0 V for exposure dose rates between 0.177 and 104 r/h should not vary more than ± 0.20 V from that predicted by

$$E_{out} = K(1.45 + \log R) \quad ,$$

where

$K = 1.45$ V

R = numerical value of exposure dose rate in r/h.

3. Response Time Test

The output voltage should reach 1.35 V in less than 15 sec when exposed to a step change in radiation rate from 0 to 0.38 r/h.

4. Automatic Calibration Test

Disconnect TP4 from TP3 of the power supply. Connect a dc module with a type I or II probe attached to the remaining J1 or J2 of the power supply. The output voltage should vary periodically in accordance with times measured in following test specification 334532-400. The voltage outputs during the automatic calibration cycle should be separated by no less than one decade equivalent radiation absorbed dose rates.

D. Post Test Procedure

Momentarily connect +28 V dc between TP2 and TP3 of the power supply to deactivate the latching relays.

APPENDIX VI – TEST SPECIFICATION
RADIATION DOSIMETER PROBE, UNIT 2, TYPE IV
SCHEMATIC NO. 334587
334587-400

A. Test Equipment

Electromagnetic radiation source having energies greater than 100 keV and capable of producing exposure dose rates of between 0.010 and 105 r/h.
Radiation dosimeter power supply as outlined by test specification 334532-400.
Dc amplifier module as outlined by test specification 334544-400.
Vacuum tube voltmeter, Electro-Instruments Model 1050, or equivalent.
Carbon resistor, 1/4 W, 5%, 300 kΩ.

B. Test Preparations

1. Connect the 300-kΩ resistor from TP1 of the dc amplifier module to chassis ground. Connect the VTVM across the resistor. Connect P1 of the dc amplifier to either J1 or 2 of the radiation dosimeter power supply. Connect TP4 to TP3 of the power supply to short out the automatic calibration voltage. Momentarily connect +28 V dc between TP1 and TP3 of the power supply to activate the latching relays. Allow at least 1/2-h warm-up time.

2. Adjust R26 (gain) and R21 (zero) of the dc amplifier module so that 0 and +5 V are indicated by the VTVM for exposure dose rates of 0.0104 and 104 r/h, respectively.

C. Tests

1. Collection Current Leakage Test

The VTVM should indicate no less than +1.6 V when the ionization chamber cavity is exposed to a 0.52 r/h exposure dose rate emanating from the electromagnetic radiation source.

2. Logarithmic Response Test

The voltage outputs between +1.0 and +5.0 V for exposure dose rates between 0.135 r/h and 104 r/h should not vary more than ± 0.20 V from that predicted by

$$E_{out} = K(1.6 + \log R) \quad ,$$

where

$K = 1.4$ V

R = numerical value of exposure dose rate in r/h.

3. Response Time Test

The output voltage should reach 1.35 V in less than 15 sec when exposed to a step change in radiation rate of from 0 to 0.31 r/h.

4. Automatic Calibration Test

Disconnect TP4 from TP3 of the power supply. Connect a dc module with a type I or II probe attached to the remaining J1 or J2 of the power supply. The output voltage should vary periodically in accordance with times measured in following test specification 334532-400. The voltage outputs during the automatic calibration cycle should be separated by no less than one decade equivalent radiation absorbed dose rates.

D. Post Test Procedure

Momentarily connect +28 V dc between TP2 and TP3 of the power supply to deactivate the latching relays.

APPENDIX VII – HUGHES AIRCRAFT COMPANY PRODUCT SPECIFICATION RADIATION DOSIMETRY EQUIPMENT

A. Scope

This specification covers radiation dosimetry equipment developed under Contract No. AF 29(601)-4607.

B. Applicable Documents

The following documents form a part of this specification in the manner and to the extent specified herein:

Military:

MIL-D-70327 Drawings, Engineering and Associated Lists

MIL-S-6644 Specifications, Equipment Contractor-Prepared

National Bureau of Standards:

NBS Handbook 54

Hughes Aircraft Company:

334532 Power Supply

334544 DC Amplifier Module

334553 Assembly, Radiation Probe, Type I

334566 Assembly, Radiation Probe, Type II

334577 Assembly. Radiation Probe, Type III

334587 Assembly, Radiation Probe, Type IV

334532-400 Test Specification Radiation Dosimeter, Power Supply Unit

334544-400 Test Specification DC Amplifier Module

334553-400 Test Specification Radiation Probe, Type I

334566-400 Test Specification Radiation Probe, Type II

334577-400 Test Specification Radiation Probe, Type III

334587-400 Test Specification Radiation Probe, Type IV

C. Requirements

1. Unit Description

The following units comprise a set of radiation dosimetry instruments:

Unit 1 – Radiation Probe, Type II (femur) is constructed in accordance with Hughes Aircraft Company Drawing No. 334566.

Unit 2 – Radiation Probe, Type IV (abdomen) is constructed in accordance with Hughes Aircraft Company Drawing No. 334587.

Unit 3 – Radiation Probe, Type I (humeri or spinal column) is constructed in accordance with the Hughes Aircraft Company Drawing No. 334553.

Unit 4 – Same as Unit 3.

Unit 5 – Radiation Probe, Type III (mediastinum) is constructed in accordance with Hughes Aircraft Company Drawing No. 334577.

Unit 6 – Power supply, including the batteries and electronic circuits for Units 1 through 5, is constructed in accordance with Hughes Aircraft Company Drawing No. 334532.

Subassembly 6A1 – Dc amplifier module is constructed in accordance with the Hughes Aircraft Company Drawing No. 334544.

Subassembly 6A2 – Identical with 6A1.

Subassembly 6A3 – Identical with 6A1.

Subassembly 6A4 – Identical with 6A1.

Subassembly 6A5 — Identical with 6A1.

Subassembly 6A6 — Identical with 6A1.

2. Radiation Probes

a. Sensitivity — Units 1, 2, and 5 shall have a sensitivity to gamma photons which is within 25% from 0.01 to 1 rad/h and 15% from 1 to 100 rad/h of the actual rad dose rates.

Units 3 and 4 shall have a sensitivity to gamma photons which is within ± 25% from 0.025 to 1 rad/h and ± 15% from 1 to 100 rad/h of the actual rad dose rates.

b. Calibration — The radiation probes shall be constructed to permit manual calibration during laboratory checkout. In addition, Units 1 and 2 shall provide automatic electronic calibration a minimum of once every two min.

c. Sealing — The radiation probes shall be sealed against the harmful effects of foreign elements.

d. Shielding — Lead wires connected to the radiation instruments shall be properly shielded to eliminate or reduce rf interference.

e. Materials — Where applicable, the plastic material used in the probes shall be of a tissue-equivalent type. Metals shall be located as far as possible from the detecting medium.

3. Power Supply

a. Weight — The power supply complete with five modules shall not exceed 20 lb in weight.

b. Functional Requirements — (1) Batteries — Batteries shall deliver voltages as specified on applicable schematic diagrams within the limits specified in Section C-2 of Test Specification 334532-400. Batteries shall be of a mercury cell type having a useful operating time of 75 h at -20°F and an additional 75 h of operating time at temperatures between 0°F and +140°F.

(2) Calibration — Calibration circuitry shall be provided by the power supply for two of the five radiation probes in the manner described in Section C-2-b of this Specification.

(3) Control — The power supply batteries shall be actuated by the application of 28 V dc to the coils of latching relays. The batteries shall be disconnected by the same voltage applied to the relay coils of opposite polarity.

(4) Signal Output – The signal output of each channel of radiation monitor data shall be a dc voltage in the range of 0 to 5 V. Response shall be approximately logarithmic.

4. Environmental Conditions

The radiation dosimetry equipment shall operate as specified herein under the following conditions.

a. Acceleration – The equipment shall be constructed to withstand 40 g's in all directions.

b. Vibration – The equipment shall be constructed to withstand vibration forces of 1 g from 0 to 2000 cps.

c. Temperature – The equipment shall be constructed to withstand temperatures from -20°F to +140°F.

d. Pressure – The equipment shall be required to operate at a pressure corresponding to that in evidence from 0 to 140,000 ft above sea level.

5. Interchangeability

For a given instrument listed in Section C-1 of this Specification all parts having the same manufacturer's part number shall be functionally and dimensionally interchangeable.

6. Workmanship

This equipment shall be fabricated and finished in a manner such that criteria of appearance and fit shall be observed. Particular attention should be given to neatness and thoroughness of soldering, wiring, painting, riveting and welding, and the freedom of parts from burrs and sharp edges.

7. Drawings and Specifications

Drawings describing this equipment shall be prepared in accordance with MIL-D-70327, Type I. Specifications describing this equipment shall be prepared using MIL-S-6644 as a guide for format only.

8. Construction

Construction shall be in accordance with engineering drawings referenced herein.

D. Quality Assurance

1. Acceptance Tests

The Air Force shall conduct all acceptance tests. Acceptance shall be rated on equipment being demonstrated to meet the operational, performance, and test requirements stated herein to the satisfaction of the Air Force Project Engineer.

2. Applicable Test Specifications

The power supply chassis shall be tested prior to delivery in accordance with Test Specification 334532-400.

The individual dc amplifier modules shall be tested prior to delivery in accordance with Test Specification 334544-400.

The individual radiation probes shall be tested prior to delivery in accordance with Test Specification 334553-400, 334577-400, 334566-400, or 334587-400, whichever is applicable.

E. Preparation for Delivery

The radiation dosimetry equipment shall be prepared for delivery in accordance with best commercial practice.

F. Notes

The unit of dose and dose rates for the purpose of this Specification shall be the rad as defined in NBS Handbook 54.

The radiation source used to determine instrument sensitivity as specified in Paragraph C-2-a of this specification shall be Cs^{137}, or alternatively, Co^{60}.

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Unclassified Report

An instrumentation system to measure the absorbed dose due to ionizing radiations has been designed for use with a tissue-equivalent manikin in space flights. The ionization chambers to be described are fabricated from tissue-equivalent materials to match those of the manikin and conform in design to the Bragg-Gray principle. Experimental curves show saturation conditions, pressure extrapolations, and directional dependence. Further, the design has minimized directional

1. Dosage rates
2. Dosimeters
3. Ionization
4. Radiation effects--measurement
5. Space environment
6. Tissues -- effects of radiation

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II. Contract AF 29(501)-4607
III. Hughes Research Labs. Hughes Aircraft Co., Malibu, Calif.
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dependence with average losses ranging from 5 to 20 percent due to shielding of the first-stage electronics, which have been incorporated directly with the ionization chamber. The electrical signal generated by the radiation absorbed dose rate as recorded by the chambers is then processed electronically and telemetered back to earth. The electronic instrumentation functions continuously over a dose range of 0.01 to 100 rads per hour and has a logarithmic response. The chambers are designed to be placed in the tissue-equivalent manikin at the following sites: femur, abdomen, mediastinum, humeri, and spinal column. Automatic calibration is provided for in both the femur and abdomen electronics. The calibration data were obtained by using the gamma rays emitted by cobalt-60.

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